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An overview of stygobiontic invertebrates of Poland based on published data

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Abstract

Based on published literature, at least eighty species of stygobiontic invertebrates are confirmed in Poland. The highest number of these species is found in interstitial waters and wells, while a lower number was discovered in caves and springs. Hydrachnidia is represented by 45 species living mainly in interstitial waters, Crustacea by 24, Annelida by eleven species, while Turbellaria and Gastropoda are each represented by one species. As many as 14 endemic species were described from Poland but the taxonomical status of some of them is unclear. The highest number of stygobionts was stated in southern part of Poland, an area onto which most of the studies were focused on.

Keywords

subterranean fauna, checklist, caves, wells, springs, interstitial waters

Introduction

Various classifications of subterranean aquatic habitats were made over the years (e.g., Thienemann 1926, Botosaneanu 1986) and occasionally some have been evaluated (Culver and Pipan 2011, Gutjahr et al. 2014). Stygobiontic invertebrates inhabit shallow underground waters, access to which is possible through caves, springs, and wells (Gibert et al. 1994, Gunn 2004) as well as through other man-made subterranean habitats such as adits, shafts or mines. Moreover, obligate subterranean fauna living in interstitial waters beneath streams and rivers (the hyporheic zone) and in the spaces among alluvial sediments deposited along the banks also is recognized as stygobiontic.

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Literature reviews of subterranean invertebrates have been published from different perspectives, including a focus on obligate subterranean fauna in one country (Reboleira et al. 2012), for the whole cave fauna in one country (Strouhal and Vornatscher 1975, Kováč et al. 2014) or for particular taxonomic groups in selected geographic regions, such as shrimps (Anker 2008) or annelids (Martínez-Ansemíl et al. 2016, Artheau and Giani 2006).

In Poland, the southern part of the country has been the focus area for studies involving aquatic subterranean fauna and, to a lesser degree, the central parts of the country; unfortunately, there is little to no information from the northern regions. Moreover, for some taxonomic groups with stygobionts there are no detailed studies – i.e. there is almost a complete lack of information concerning Turbellaria and Copepoda. Even in the case of the Amphipoda, intensively investigated by Skalski (Table 1; entry no. 73–79, Hydrachnidia studied by Biesiadka (Table 1; entry no. 2–7, 9) and Ostracoda studied by Sywula and Namiotko (Table 1; entry no. 1, 64, 85–88, 90, 91) there have been no publications in recent years. Only Oligochaeta (Table 1; no 14–24, 28, 30–33, 35, 42–44, 46–48, 63) have been studied by Dumnicka and co-workers up to now. The only checklist of Polish troglobionts and stygobionts was compiled by Skalski (1981) as an appendix in a local journal. He stated the presence of 54 species. Thus, there is a need, after more than 35 years, to compile and update the list of stygobionts.

Methods

Species found on the present territory of Poland were taken into consideration. Papers with data concerning Polish aquatic subterranean fauna are scattered. We reviewed journal literature, conference abstracts, and monographs, but did not include synopses, reviews and syntheses based on previously published original papers.

Species names follow Fauna Europea (http://www.faunaeur.org). When the species is not included in Fauna Europea or incorrect information was published in it (as in the case of *Crangonyx paxi* – see Table 1) "Fauna of Poland" (Bogdanowicz et al., 2004, 2008) was referred to.

Results

Source publications and analysis of species taxonomical status

The literature concerning Polish invertebrate fauna from subterranean waters (including stygophiles and stygoxenes) is limited. Since the end of the 19th century, when the description of *Niphargus tatrensis* was published (Table 1; entry no 95), around 100 papers have contributed to the stygobiontic fauna of Poland. Relatively few studies reported on the fauna of subterranean waters prior to the 1960s, with most publications occurring from 1960 to 1999 (Fig. 1).

Table 1. List of stygobiontic species known of Poland and their association with the geographic regions and habitats. Abbreviations of geographic names: B. – Beskid Mts; K.-Cz. – Kraków-Częstochowa; Depr. – Depression; Lakel. – Lakeland; Up. – Upland; Val. – Valley. Abbreviations of habitat names: AS – artificial subterranean habitats; C – caves; HR – hypotelminorheic habitat; I – interstitial waters; SP – springs; SW – surface waters; W – wells.

Group/ Species	Region	Habitat	References
Tricladida			
Dendrocoelum cf. *carpaticum* Komarek, 1919	Małopolska Gap	W	79
Annelida			
Troglochaetus beranecki Delachaux, 1921	Kłodzko Basin	C	84
Cernosvitoviella parviseta Gadzińska, 1974	Łask Up., Kłodzko Basin, B. Śląski Mts, Tatra Mts	C,W	20, 23, 30, 35
Enchytraeus dominicae Dumnicka, 1976 E	K.-Cz. Up., Tatra Mts, Świętokrzyskie Mts, Kłodzko Basin, Łask Up.	C, W, I	14, 16, 20, 33
Enchytraeus polonicus Dumnicka, 1977 E	K.-Cz. Up.	C	15, 17
Gianius aquaedulcis (Hrabě, 1960)	K.-Cz. Up.	SP	24
Haber speciosus (Hrabě, 1931)	B. Śląski Mts	W	42
Rhyacodrilus subterraneus Hrabě, 1963	K.-Cz. Up., Ełk Lakel.	W, I	28, 29
Trichodrilus cernosvitovi Hrabě, 1937	Tatra Mts, Pieniny Mts, K.-Cz. Up.	I, SP, SW	20, 22, 47, 48
Trichodrilus moravicus Hrabě, 1937	Tatra, B. Śląski Mts, Pieniny Mts, K.-Cz. Up., Kłodzko Basin	C, I, SW, W	18, 20, 23, 28, 47
Trichodrilus pragensis Vejdovský, 1876	Kłodzko Basin	C	20
Trichodrilus spelaeus Moszyński, 1936 E	Kłodzko Basin	AS	63
Trichodrilus sp. juv. Claparède, 1862	Małopolska Gap	W	X
Amphipoda			
Crangonyx paxi § Schellenberg, 1935 E	Kłodzko Basin	AS, SP	71, 82
Gammarus pulex polonensis Karaman & Pinkster, 1977 E	Poznań Lakel.	I	41
Niphargus ? *aquilex* Schiödte, 1856	Central Oder Val.	W	37
Niphargus casimiriensis Skalski, 1980 E	Małopolska Gap	W, SP	79
Niphargus inopinatus Schellenberg, 1932	Tatra Mts	SP	73
Niphargus leopoliensis Jaworowski, 1893	Bieszczady Mts, K.-Cz. Up. Jędrzejów Plateau	SW, W	73, 76
Niphargus puteanus† Koch, 1836	Wałbrzych Mts, Central Oder Val.	C, SW, I	65
Niphargus tatrensis Wrześniowski, 1888	K.-Cz. Up., Orava-Podhale Depr., Tatra, B. Żywiecki, B. Śląski, B. Mały, B. Wyspowy, B. Niski, Gorce, Bieszczady Mts, Kłodzko Basin, Małopolska Gap	I, W, SP, C, SW	10, 11, 18, 22, 28, 31, 36, 59, 60, 69, 72, 74, 75, 76, 77, 79, 80, 84, 96, 97
Niphargellus arndti (Schellenberg, 1933)	Wałbrzych Mts, Kłodzko Basin	C, AS	38, 58, 70
Synurella tenebrarum (Wrześniowski, 1888)	Orava-Podhale Depr.	W	95
Synurella coeca | Dobreanu & Manolache, 1951	Małopolska Gap	W	79
Bathynellacea			
Bathynella natans Vejdovský, 1882	Kłodzko Basin, Orava-Podhale Depr.	I	89
Isopoda			
Proasellus slavus (Remy, 1948)	Orava-Podhale Depr.	I, W	89
Copepoda			
Acanthocyclops rhenanus Kiefer, 1936	Łask Up.	SW	92

Group/ Species	Region	Habitat	References
Diacyclops clandestinus (Kiefer, 1926)	Tatra Mts, Oświęcim Basin	C, W	11, 57
Graeteriella unisetigera (Graeter, 1908)	Central Oder Val.	W	94
Ostracoda			
Cryptocandona matris (Sywula, 1976)	Małopolska Gap, Silesian Foothill, B. Wschodni Mts, Pieniny Mts	W, I	1, 79, 87, 90, 91
Cyclocypris sp. Brady & Norman, 1889	B. Wyspowy Mts	I	85
Fabaeformiscandona latens (Klie, 1940)	Gorce Mts	SP	86
Fabaeformiscandona wegelini (Petkovski, 1962)	Vistula catch. down to Kazimierz Dolny town, Gorce Mts, Oder catch. down to outlet of Warta	W, I, SW	79, 85
Nannocandona stygia Sywula, 1976 E	Sudety Mts, B. Śląski Mts	W, I	87
Pseudocandona eremita (Vejdovský1882)	Małopolska Gap, Vistula Fen Country, Central Oder Val., Bóbr R. catchment	W, SW, I	64, 79, 88
Pseudocandona mira (Sywula, 1976) E	B. Żywiecki Mts, Orava-Podhale Depr.	W	87
Pseudocandona szoecsi Farkas, 1958	Małopolska Gap, Orava-Podhale Depr.	W	79, 88
Hydrachnidia			
Albaxona elegans Walter, 1947	Bieszczady Mts	I	7
Albaxona lundbladi Motas & Tanasachi, 1947 = *A. gracilis* Schwoerbel, 1962 (sensu Bogdanowicz et al. 2008)	Bieszczady Mts	I	7
Albaxona minuta Szalay, 1944	Bieszczady Mts	I	83
Arrenurus corsicus Angelier, 1951	Central Oder Val.	W	5
Atractides barbarae Biesiadka, 1972 E	B. Wyspowy Mts	I	4
Atractides gorcensis Biesiadka, 1972	Gorce Mts	I	2
Atractides latipalpis Motas & Tanasachi, 1946	Tatra Mts	I	5
Atractides latipes (Szalay, 1935)	B. Wyspowy, Bieszczady Mts, Wieliczka Foothills	I	3, 83
Atractides phreaticus (Motas & Tanasachi, 1948)	Pieniny Mts, B. Wyspowy Mts, Bieszczady Mts, Range of Babia Góra	I, SW	3, 6, 83, 96
Atractides pilosus Schwoerbel, 1961 = *A. tener* ? sensu Gerecke, 2003	Orava-Podhale Depr.	I	5
Atractides pumilus (Szalay, 1946) = *A. primitivus* (Walter, 1947) sensu Gerecke, 2003	Orava-Podhale Depr., Pieniny Mts, Bieszczady Mts	I	5, 6, 83
Atractides sokolowi (Motas & Tanasachi, 1948)	Pieniny Mts, Bieszczady Mts	I	6, 9
Aturus karamani Viets, 1936	Tatra Mts	I	5
Aturus paucisetus Motas & Tanasachi, 1946	Gorce Mts, Pieniny Mts, Bieszczady Mts	I	3, 6, 83
Aturus petrophilus Biesiadka, 1979‡ E	Pieniny Mts	I	6
Aturus pulchellus Biesiadka, 1975 E	Tatra Mts	I	5
Axonopsis cogitatus Biesiadka, 1975	Orava-Podhale Depr.	I	5
Axonopsis inferorum Motas & Tanasachi, 1947	B. Wschodni Mts	I	5
Axonopsis vietsi Motas & Tanasachi, 1947	Bieszczady Mts	I	83
Barbaxonella angulata (Viets, 1955)	Bieszczady Mts	I	7
Erebaxonopsis brevipes Motas & Tanasachi, 1947	B. Wschodni Mts	I	5, 83
Feltria mira (Motas & Tanasachi, 1948)	Orava-Podhale Depr., Tatra, B. Wyspowy Mts	I	3, 5
Feltria subterranea Viets, 1937	Bieszczady Mts	I	7
Frontipodopsis reticulatifrons Szalay, 1945	Bieszczady, Pieniny Mts	I, SW	5, 6, 83

Group/ Species	Region	Habitat	References
Hungarohydracarus subterraneus Szalay, 1943	B. Żywiecki Mts, Bieszczady Mts	I	5, 83
Kawamuracarus chappuisi Motas & Tanasachi, 1946	Orava-Podhale Depr.	I, W	5
Kongsbergia alata Szalay, 1954	Central Oder Val.	I	5
Kongsbergia arenaria Angelier, 1951	Orava-Podhale Depr., Bieszczady Mts	I	7
Kongsbergia clypeata Szalay, 1945	Bieszczady Mts	I	7
Kongsbergia dentata Walter, 1947	Tatra Mts, Pieniny Mts	I	5, 6
Kongsbergia d-motasi Motas & Tanasachi, 1958	Bieszczady Mts	I	7
Kongsbergia lundbladi Szalay, 1956	Bieszczady Mts	I	Biesiadka pers. com.
Kongsbergia pectinata Walter, 1947	Bieszczady Mts, Gorce Mts	I, SW	3, 83
Kongsbergia ruttneri Walter, 1930	Pieniny Mts	I	6
Kongsbergia wroblewskii ‡ Biesiadka, 1997 E	Bieszczady Mts	I	7
Lethaxona cavifrons Szalay, 1943	Orava-Podhale Depr., B. Wschodni Mts, Pieniny Mts, Gorce Mts	I	3, 4, 5, 6
Lethaxona pygmea Viets, 1932	Bieszczady Mts, Gorce Mts	I	7, 83
Neoacarus hibernicus Halbert, 1944	Orava-Podhale Depr. B. Wschodni Mts, B. Wyspowy Mts, Pieniny Mts	I	3, 5, 6
Neumania phreaticola Motas & Tanasachi, 1948	Bieszczady Mts	I	7
Sperchonopsis phreaticus Biesiadka, 1975 E	Tatra Mts, Bieszczady Mts	I	5, 83
Stygomononia latipes Szalay, 1943	Bieszczady, Pieniny, Tatra, B. Żywiecki, B. Wyspowy Mts, Kłodzko Basin	I	3, 5, 6, 83, 96
Wandesia thori Schechtel, 1912	Tatra Mts, Gorce Mts	SW	67, 68
Wandesia stygophila Szalay, 1944	Bieszczady Mts	I	83
Halacaroidea			
Loboharacarus weberi quadriporus Walter, 1947	B. Żywiecki, Pieniny, B. Wschodni Mts, Tatra Mts, Orava- Podhale Depr.	I	5, 6
Parasoldanellonyx parviscutatus (Walter, 1917)	Orava-Podhale Depr.	W	5
Gastropoda			
Falniowskia neglectissima Falniowski & Steffek, 1989 E	K-Cz. Up.	HR	34

†– misidentification, ‡ – nomen nudum; § – species known from Kłodzko Basin only, localization in Germany is false (Fauna Europaea); | – described as *S. coeca rafalskii* by Skalski (1981); E – species endemic to Poland; x – leg. A. Skalski 14.07.1977, det. E. Dumnicka.

Several factors make it difficult to come up with an exact number of Polish stygobionts. First, among species found only once many years ago, a few probably were not correctly determined (e.g., *Niphargus puteanus*) or exactly determined (*N.* cf. *inopinatus* and *Dendrocoelum* cf. *carphaticum*) (Table 1). Second, the taxonomic position of some species from various groups is not clear due to numerous subsequent taxonomic revisions. For example *Enchytraeus polonicus* (Oligochaeta) is treated by Schmelz and Collado (2010) as a cave population (with an additional pair of spermathecae) of a very common species *E. buchholzi*. Two forms of *Synurella ambulans* (*S. ambulans* f. *subterranea* and *S. ambulans* f. *tenebrarum*) were considered in Polish literature as stygobionts. Now, these forms are not listed in Fauna Europea, while in WoRMS (http://

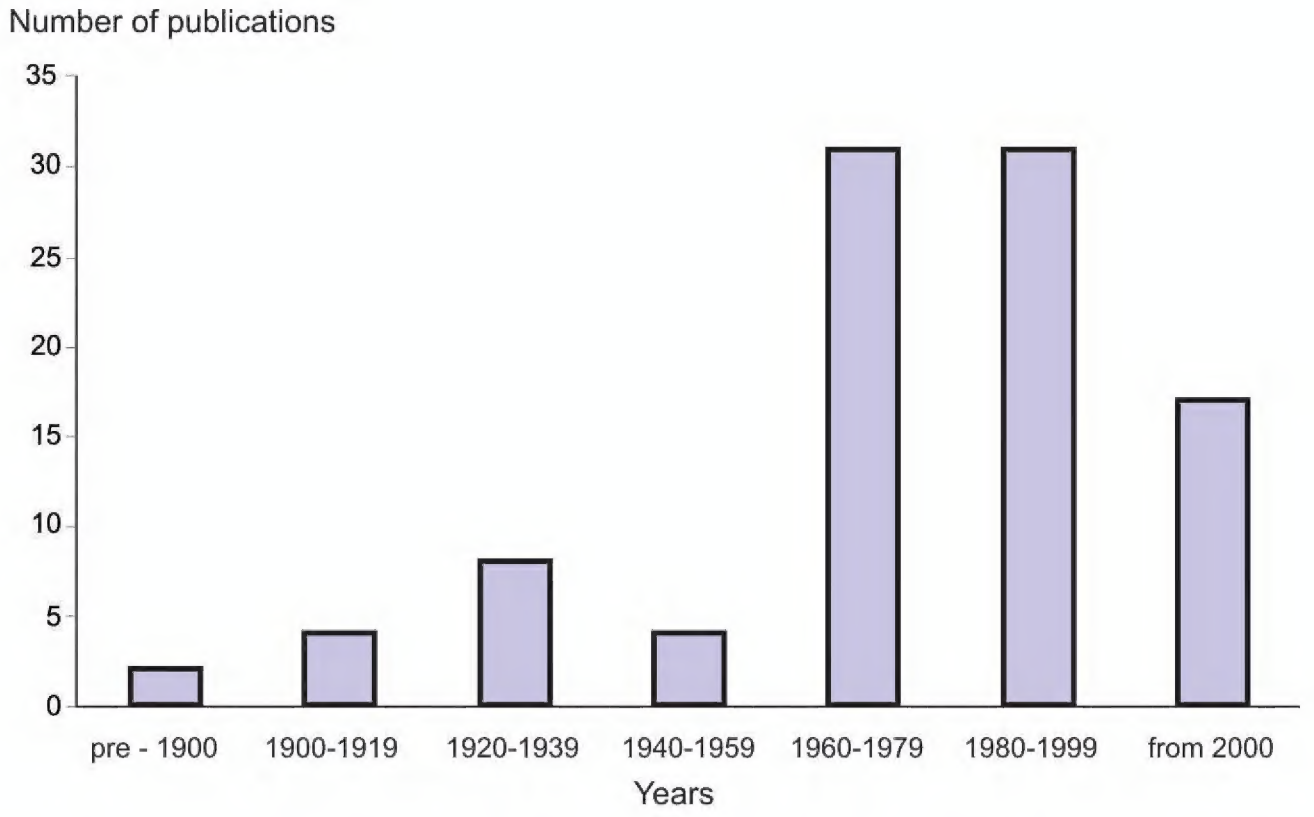

Figure 1. Number of publications concerning subterranean aquatic fauna of Poland through time.

www.marinespecies.org/) *S. ambulans* f. *tenebrarum* is elevated to the species level (as *S. tenebrarum*). This species is listed in the Table 1. Moreover, two species of Hydrachnidia (*Aturus petrophilus* Biesiadka 1979 and *Kongsbergia wroblewskii* Biesiadka 1997) are *nomen nudum* (Biesiadka pers. com.), though the first species is included in the list of Hydrachnidia in Fauna Europea.

In some cases, so-called local stygobionts were included in the checklist (Table 1). For example, *Rhyacodrilus subterraneus* is found exclusively in subterranean waters in Poland, it is known from surface waters in northern Europe (Dumnicka 2014). Three species of Hydrachnidia known exclusively from interstitial waters in Poland are considered stygobionts (Bogdanowicz et al. 2008).

Stygobiontic species in particular taxonomic groups

Approximately eighty stygobiontic species (Table 1) are known from aquatic subterranean environments in Poland, documented in various regions of the country (Fig. 2). The detailed localities of many stygobiontic species are given in publications but for some species only the range of their occurrence was published, with no specific localities.

Turbellaria seems to be the most poorly known group of invertebrates in Poland, due in part to a lack of researchers specializing in this group. There is a record of stygobiontic *Dendrocoelum* that has not yet been verified.

The phyllum Annelida is represented by only one stygobiontic species of Polychaeta (*Troglochaetus beranecki*). It is known only from Radochowska and Rogóżka caves (Table 1; entry no. 84), but has not been found since the original report, despite intensive sampling in the Radochowska cave and in interstitial waters of nearby streams and

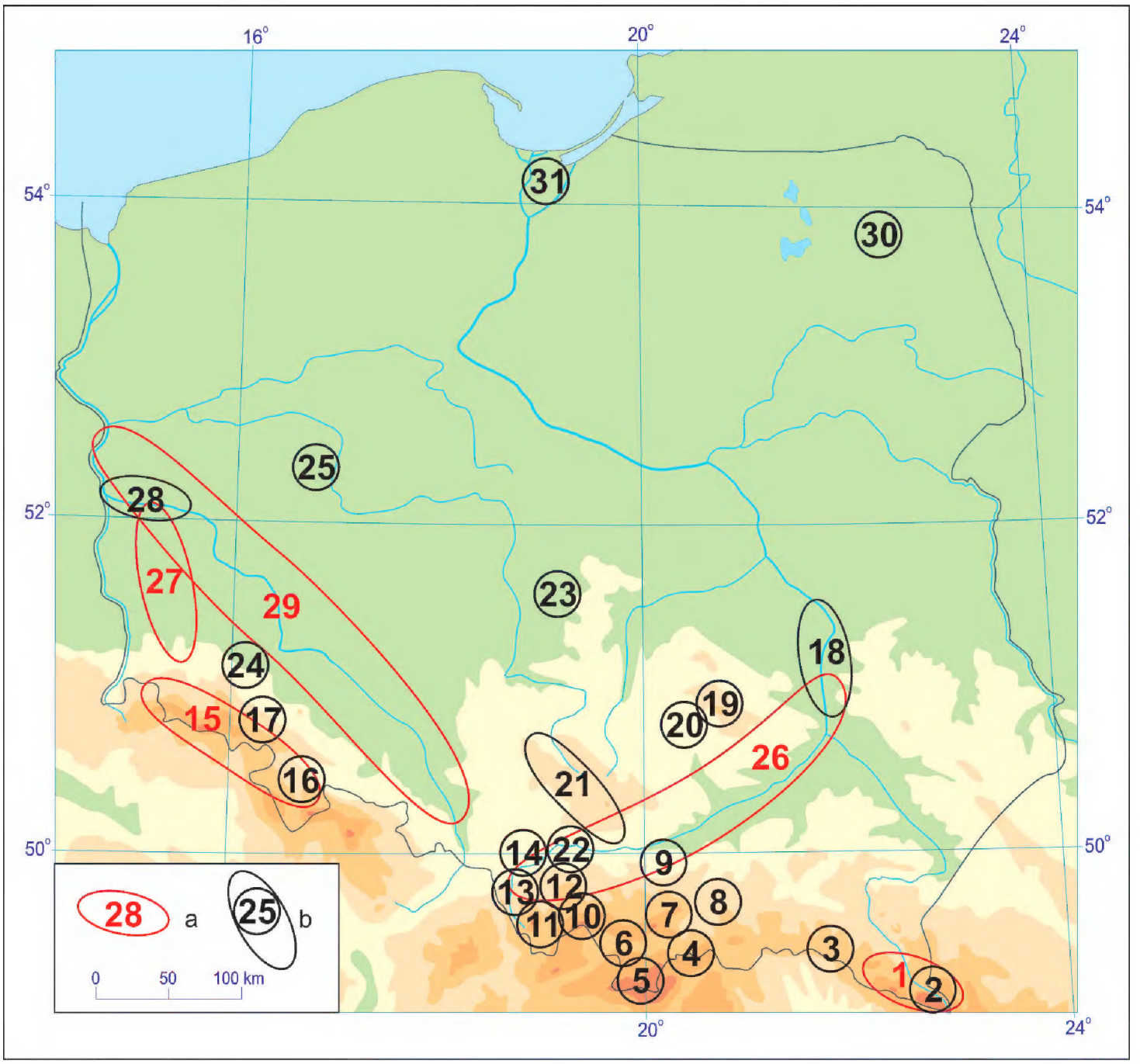

Figure 2. Regions of Poland studied by various authors: **1** Beskid Wschodni Mts. **2** Bieszczady Mts. **3** Beskid Niski Mts. **4** Pieniny Mts. **5** Tatra Mts. **6** Orava-Podhale Depression **7** Gorce Mts. **8** Beskid Wyspowy Mts. **9** Wieliczka Foothill **10** Range of Babia Góra **11** Beskid Żywiecki Mts. **12** Beskid Mały Mts. **13** Beskid Śląski Mts. **14** Silesian Foothill **15** Sudety Mts. **16** Kłodzko Basin **17** Wałbrzych Mts. **18** Małopolska Gap of the Vistula **19** Świętokrzyskie Mts. **20** Jędrzejów Plateau **21** Kraków- Częstochowa Upland **22** Oświęcim Basin **23** Łask Upland **24** Legnica Plain **25** Poznań Lakeland **26** Vistula catchment up to Kazimierz Dolny town **27** Bóbr River catchment **28** Central Oder Valley **29** Oder catchment up to the outlet of the Warta River **30** Ełk Lakeland **31** Vistula Fen Country. **a** area of species occurrence without exact localization given **b** geographical regions with detailed localization of species provided.

springs (Table 1; entry no. 20, 38, 89). At least ten stygobiontic Oligochaeta species occur in Poland, with representatives in habitats of all types. Their list and detailed distribution was recently provided (Dumnicka 2014). Moreover, juvenile specimens of *Trichodrilus* were found in materials collected by Skalski (Table 1).

Crustacea, which usually dominate in subterranean waters of south-western Europe (Danielopol et al. 2000, Deharveng et al. 2009, Sket 1999), are represented in Poland by only 24 species (Fig. 3).

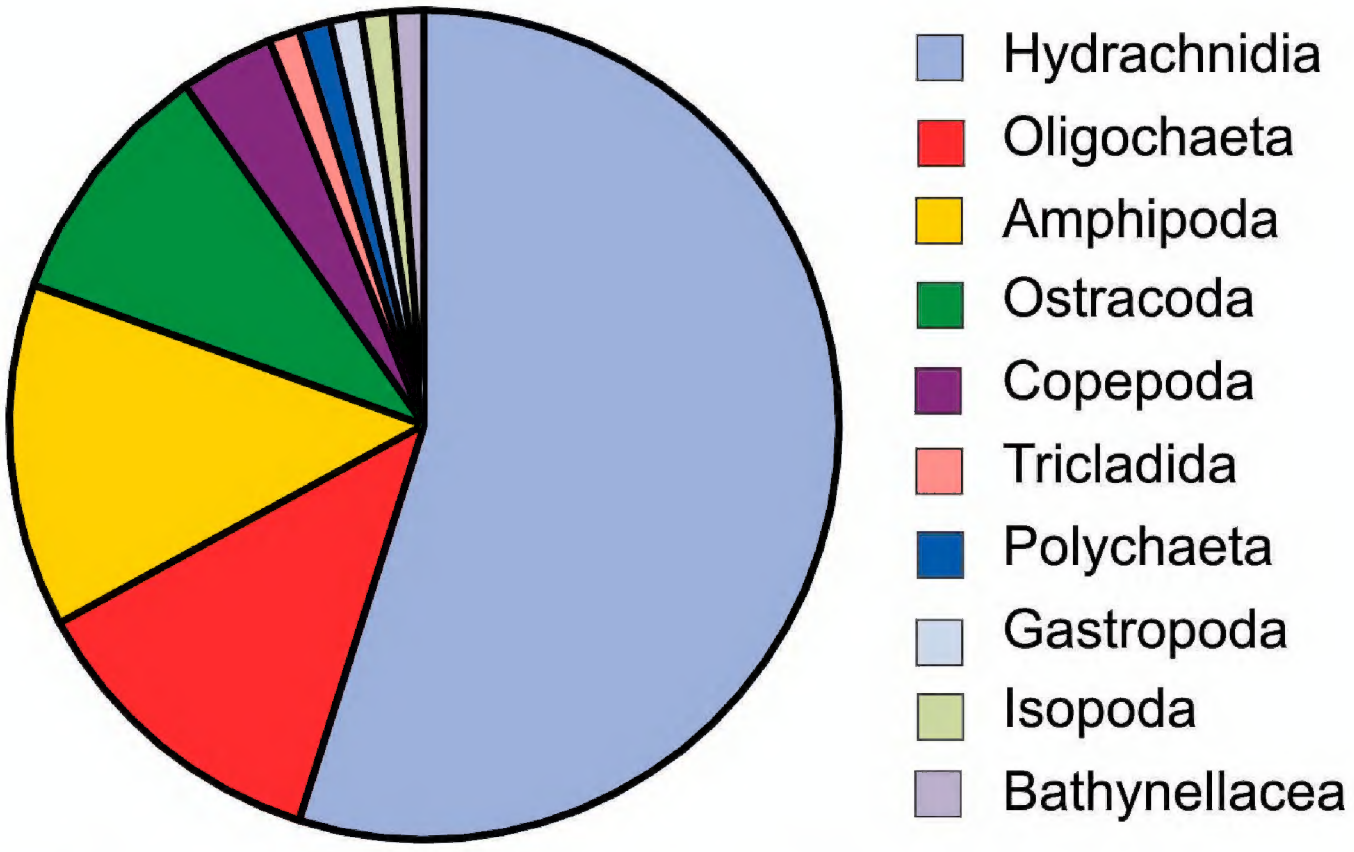

Figure 3. Percentage share of stygobiontic species from particular taxonomic groups.

Among the Amphipoda, eleven stygobiontic species have been reported, six of them belong to genus *Niphargus*. Of these, identification of *N. puteanus* (Table 1; entry no. 65) was contested by Skalski (Table 1; entry no. 77). The occurrence of two other *Niphargus* species (*Niphargus* ? *aquilex* and *N. inopinatus*) in Poland has not been confirmed in the last 100 years. For *N. inopinatus*, it is possible that the species occurs in the Polish part of the Tatra Mountains, because it was confirmed in the southern part of this mountain range, in Slovakia (http://www.zoo.sav.sk/voda_pdf/voda_pdf.htm). The most common *Niphargus* in all studied habitats is *N. tatrensis*, which is sporadically found in surface waters also (Fig. 4). This species has been repeatedly observed in some caves, especially in Tatra Mountains. Additionally, it has been recorded from piezometer samples taken in Carpathic effluents of the Vistula. However, *Niphargus tatrensis* has patchy distribution because it has not been recorded from the many sampled wells in a large area in south-eastern Poland (Table 1; entry no. 76). The only stygobiontic subspecies from genus *Gammarus* shows morphological features typical for stygobiontic species such as the absence of eyes and slender antenna and pereiopods (Table 1; entry no. 41).

The remaining orders of Malacostraca: Bathynellacea and Isopoda are each represented by one species (*Bathynella natans* and *Proasellus slavus*, respectively) (Table 1), and are rarely found in interstitial waters. Both species have also been recorded from wells.

None of the eight stygobiontic species of ostracods known from Poland have been recorded from cave waters. Instead, stygobiontic Ostracoda have been collected most frequently from wells and interstitial waters (Table 1). Two species have wide distribution (*Fabaeformiscandona wegelini*, *Pseudocandona eremita*) while the remaining have been stated only in southern Poland. Stygobiontic Copepoda have been poorly studied

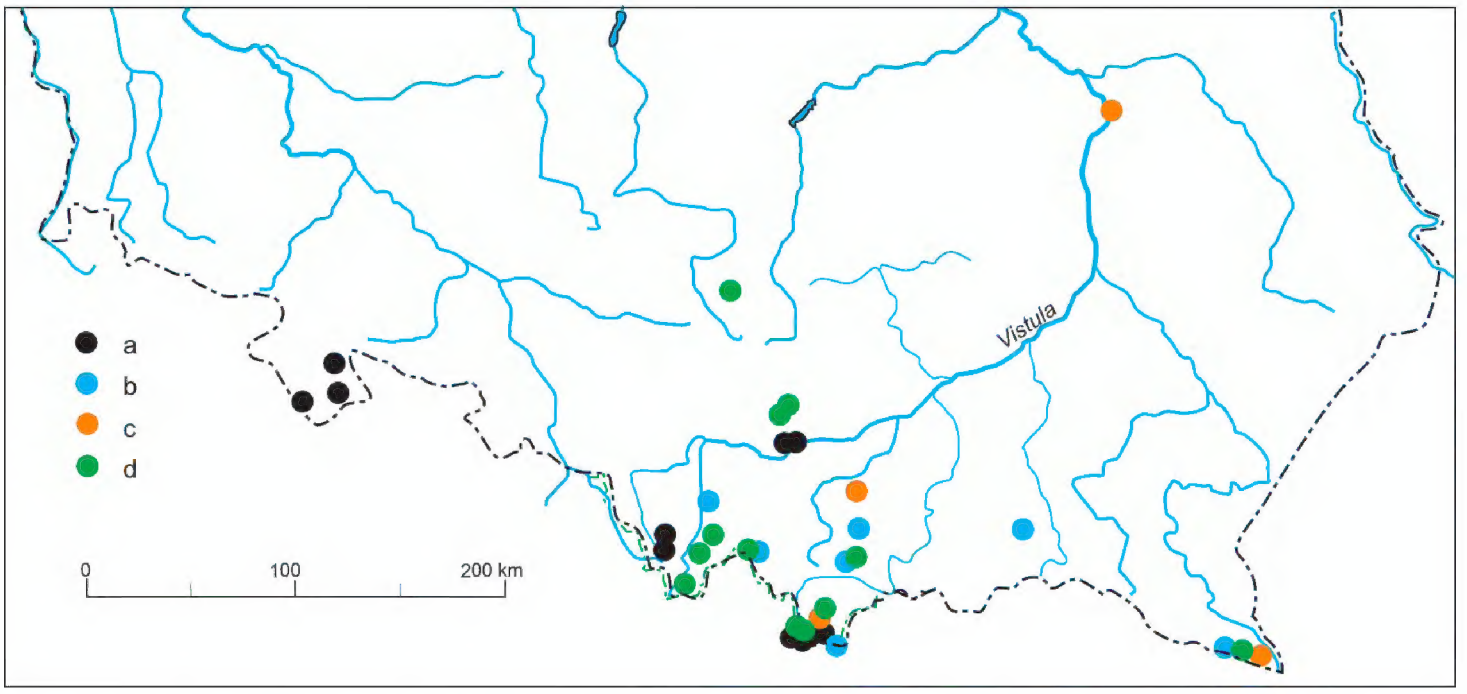

Figure 4. Distribution of *Niphargus tatrensis* in various habitats in Poland; **a** caves **b** surface waters **c** wells **d** springs.

in Poland, with only three species reported in subterranean waters. There is no published data on Harpacticoida, which is likely due to their occurrence predominantly in interstitial and epikarstic waters.

Mites, represented by Hydrachnidia (43 species) and Halacaroidea (two species) constitute over 50% of all stygobiontic species in Poland (Fig. 3). They inhabit almost exclusively (42 species) interstitial waters, but a few species have been reported from wells and surface waters. *Wandesia thori*, considered a stygobiontic species (Bogdanowicz et al. 2008, Botosaneanu 1986) was described from bottom samples collected in streams from the Tatra Mountains (Table 1; entry no. 67) and yet it has also been reported in a spring and two spring brooks in Gorce Mountains (Table 1; entry no. 68).

A species of Hydrobiidae (Gastropoda), *Falniowskia neglectissima*, has been described from wet litter covering the ground (Table 1; entry no. 34) and it is treated as a stygobiont living in the hypothelminorheic habitat (Culver and Pipan 2011).

Our review indicates that 14 endemic species (including two *nomen nudum*) have been described from Poland: three Oligochaeta, five Crustacea, five Hydrachnidia and one Gastropoda. Some of these have broad distributions, such as *Enchytraeus dominicae* (Table 1), while most of the 14 endemics described from the country are known from only one region.

Species richness in particular habitats

Of all the groundwater habitats, cave waters have been the most intensively investigated in Poland, yet the number of records of stygobiontic species from Polish caves is relatively low (Fig. 5), a pattern also observed in Slovakia (Kováč et al. 2014). In many caves of Poland, no stygobiontic species have been found (Table 1; entry no.

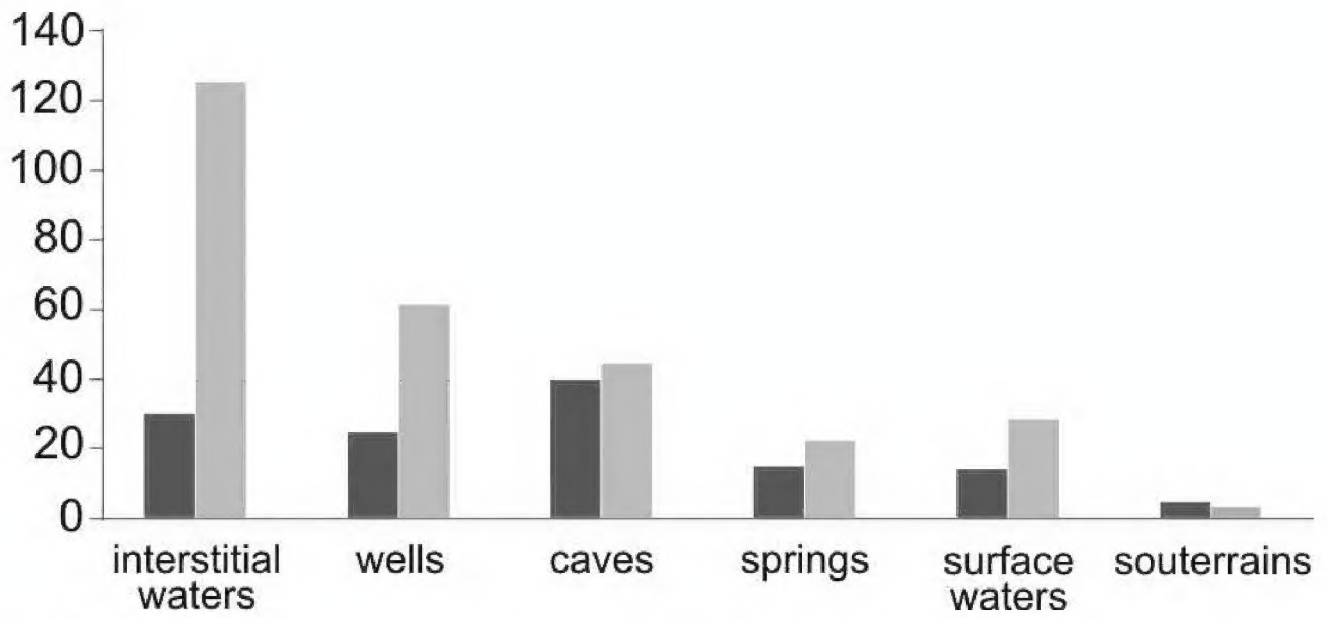

Figure 5. Number of studies performed in particular habitats (dark bar) and number of records of stygobiontic species found in them (light bar).

32), and in some cases aquatic fauna appeared to be totally absent (Kur et al. 2016). In contrast, interstitial waters of Poland contain numerous stygobiontic species, especially Hydrachnidia. Records of subterranean fauna collected from wells are relatively numerous, although this habitat seldom has been studied.

Conclusions

1. In Poland, the stygobiontic fauna proved to be unexpectedly rich in comparison to that of Belgium (Martin et al. 2009), while the more intensively studied subterranean waters of Germany have revealed a greater number of species (Hahn and Fuchs 2009). The comparison of richness of stygobiontic fauna with that stated in other neighboring countries is difficult. In Slovakia some invertebrate groups have barely been investigated in the subterranean habitat e.g. Hydrachnidia, whereas other groups such as Copepoda have been studied in more detail (Košel 2009, Juberthie et al. 2001, http://www.zoo.sav.sk/voda_pdf/voda_pdf.htm). The situation is similar in the Czech Republic, where Harpacticoida were intensively studied by Štěrba (1964, 1965, 1968) and a list of stygobionts was prepared by Bosák et al. (2001). In adjacent countries across the eastern border of Poland such studies are limited.
2. More intensive studies of stygobiontic species in Poland's interstitial waters and wells are needed because these habitats are threatened by river regulations and abandonment of wells use. In addition, some regions of Poland have been poorly studied with regard to the stygobiontic fauna, especially in northern part of the country (see Fig. 2), and more effort should be dedicated to investigating these understudied regions.
3. Due to the decline in the number of active taxonomists in recent years, the status of some stygobiontic species remains unclear. Additional societal support for taxonomic research is needed so that various groups in need of revision can be studied.

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